AD-A187 459 AIR TEMPERATURE SHIELD TESTS(U) WOODS HOLE OCEANOGRAPHIC INSTITUTION MA R E PAYNE OCT 87 WHOI-87-40 N00014-84-C-0134 1/1

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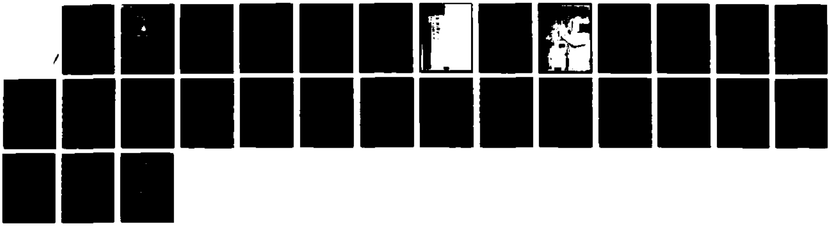

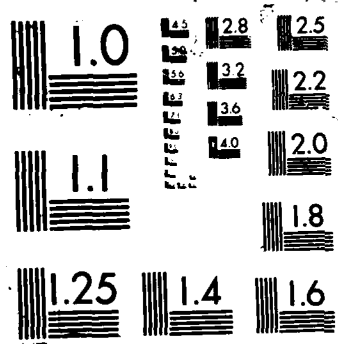
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WHOI-87-40

Woods Hole Oceanographic Institution

Air Temperature Shield Tests

by

Richard E. Payne

October 1987

Technical Report

Funding was provided by the National Science Foundation under grant Numbers OCE 81-22061 and OCE 82-11108, and by the Office of Naval Research under contract Number N00014-84-C-0134.

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Approved for Distribution:

Robert C Beardsley

Robert C. Beardsley, Chairman
Department of Physical Oceanography

ABSTRACT

Measurements were made with a group of sensors for 37 days at the end of a dock in Vineyard Sound. The sensors included: a thermistor in an R. M. Young aspirated air temperature radiation shield, a thermistor in an R. M. Young multiplate shield, wind speed and direction, and solar irradiance. For the last eight days we also included a WHOI built cylindrical radiation shield. For wind speeds above 2 m s^{-1}, the multiplate shield had an RMS error relative to the aspirated shield of 0.2-0.3 C during daylight hours. Adding a correction linear in solar irradiance decreased the error by a factor of one third to one half. The cylindrical shield appears to have performed better than this but there was insufficient data to support this conclusion statistically.

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Introduction

For remote locations, such as buoys, where electrical power is precious, the use of static shields to protect air temperature and relative humidity sensors from solar radiation is necessary rather than forced aspiration of the sensor. The degree of protection afforded by these shields, however, depends on sun altitude, solar radiation flux, wind speed, and long wave radiation from their immediate environment.

Because of the manufacturer's performance specifications, convenience of mounting our sensors, and cost, we selected R. M. Young's Model 41001 Gill Multiplate radiation shield to house both air temperature and relative humidity sensors for the Meteorological Recorder (MR) (Payne, 1987). In order to obtain an indication of their performance under reasonably realistic conditions, we carried out the informal test described in this report. A second type of shield, built at WHOI (Woods Hole Oceanographic Institution), was added during the last nine days of the test.

Test Environment

Figure 1 shows a small pier which projects about 25 m into Nantucket Sound. The wooden framework at the end was added for the purposes of the radiation shield test. The shore runs roughly east-west so that the prevailing southwest wind is onshore. The closest land to the SW is several miles away. The end of the dock thus provides a suitable marine environment for testing buoy instrumentation.

Digitization and Recording

Digitization and recording were accomplished with a standard MR. Analog data were averaged over 64 digitizations per 7.5 minute recording interval. The AIR barometer transferred a digital pressure to the MR. The wind processor computed vector components digitally and passed them to the MR. The data were recorded on digital cassettes. About once per week the tapes were changed and the data processed.

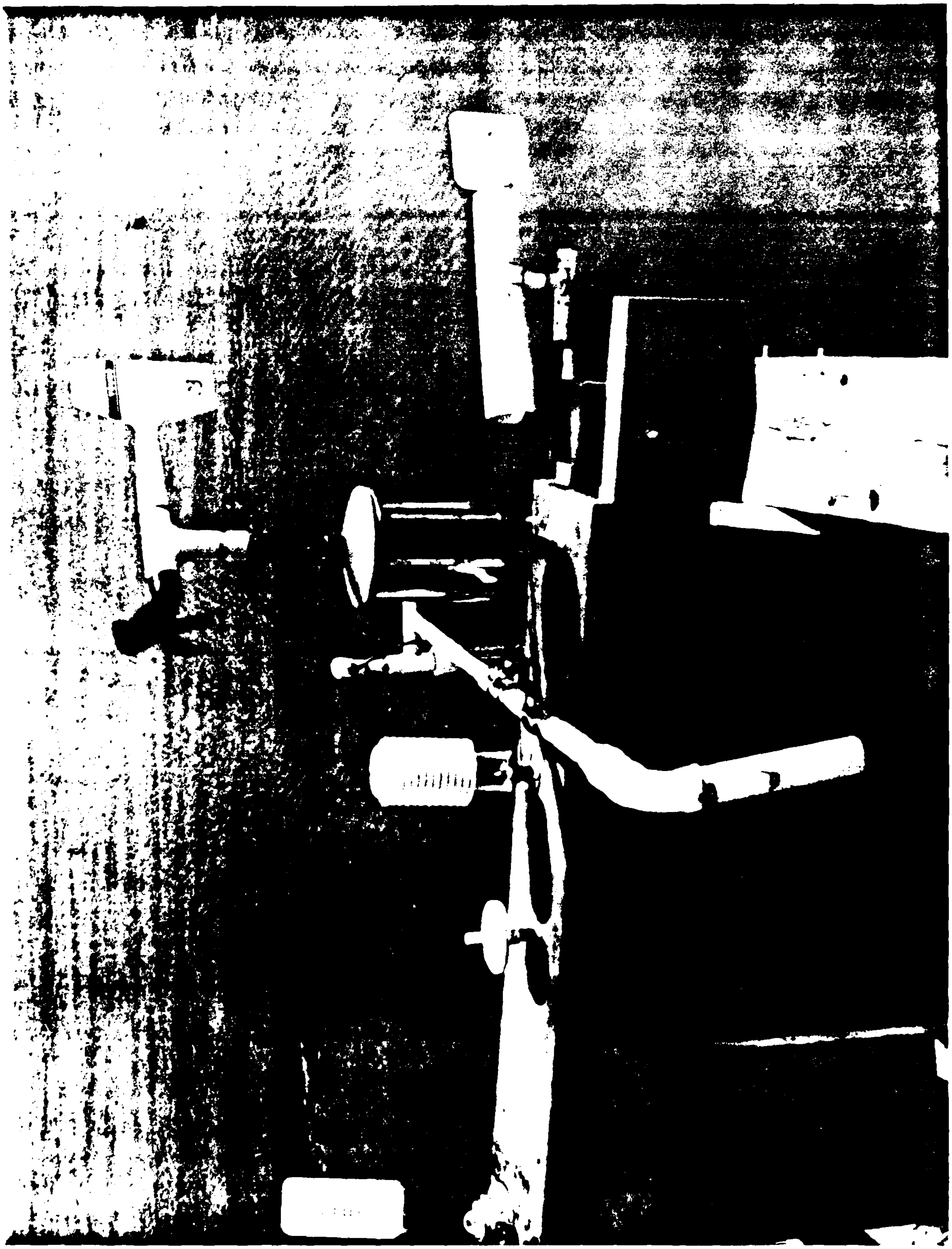
Figure 1

Sensors and Shields

Figure 2 shows the sensors as mounted on the pier. From left to right are the pyranometer, a static port for the AIR barometer, the Gill Multiplate radiation shield, a Gill-Aspirated radiation shield, a Young wind monitor atop a housing containing digital vector averaging electronics, and a WHOI-constructed radiation shield designed by J. Dean which we refer to as the Dean shield. Temperature sensors in all three radiation shields are YSI thermistors.

The R. M. Young Model 43404A Gill-Aspirated Temperature Radiation Shield provided the reference air temperature. Manufacturer's specifications state that, using the supplied fan to supply an air flow of 3 m s^{-1}, the sensor is maintained within +-.05 C of true air temperature. Unfortunately, the R. M. Young supplied fan requires 110 VAC which was not available on the pier. We substituted a 12 VDC fan which was able to maintain an air flow of only 0.7 m s^{-1}. We do not know how much this degraded the performance. The sensor is surrounded by a vacuum bottle, silvered on the inside surfaces The bottle is open at the bottom end. Gerald Gill found in wind tunnel tests (R. M. Young, personal communication) that at low wind speeds, intense infrared radiation from below could increase the apparent air temperature by as much as 1.5°C. In our situation the bottle opening pointed straight down at the water surface and we expect little error from admitted radiation except for clear sky and high sun when sun glitter may have been reflected into it. We cannot estimate the possible degradation in accuracy from this but, since the other shields are independent of this effect, we would expect to see anomalously high values of aspirated air temperature if this effect were significant. We do not.

The Young multiplate shield is designed to prevent direct solar radiation from reaching the sensor and to provide several layers of plates, with spaces between for air to circulate freely, to minimize the effects of long wave radiation from the uppermost and lowermost plates on the sensor. The plates are molded of plastic. The thermistor is potted in a 1/4" bolt which screws into a Delrin cylinder. There is approximately 1/16" of plastic between the bolt and ambient air. The thermistor is calibrated to an accuracy of 0.01C absolute (Payne et al., 1976). We estimate that self heating,



digitization, and analog electronics (Payne, 1987) increase the uncertainty to 0.05C.

The Dean radiation shield, described fully in Dean and Beardsley (1987), is built of three concentric tubes, one each of Surlyn, PVC and aluminum from the outside in. It was designed to act as a wind vane, pivoting freely to stay aligned into the wind to allow direct air flow across the temperature sensor and between the tubes. The thermistor used was similar to those in the multiplate shields and was also calibrated to 0.01 C.

The pyranometer is an Eppley Model 8-48. Due to foreshortening in the photograph it appears to be closer to the other sensors than it was. They were all quite low in its field of view. We estimate that the irradiance measurements were accurate to about 5%.

The R. M. Young Model 5102 Wind Monitor was mounted on a housing which contained a microprocessor-based wind processor (WP). On buoy deployments the WP contains a magnetic compass. On the pier we hardwired a compass reading of "0" and aligned the case to magnetic north. The WP computes vector components for each propeller revolution (30 cm of air) and sums them over the recording interval, giving a true vector average. R. M. Young indicates that accuracies are approximately $\pm 2\%$ in wind speed and ± 2 degrees in wind direction.

Barometric pressure measurements were not used in the analyses in this report.

The Data

Data recording began at 2036 UTC on 20 August 1985 and continue until 1745 UTC on 25 September. The Dean shield thermistor was attached to the MR midday, 17 September. Wind speed is missing for about six days. The data from a 24 hour period between 10-11 September were deleted because the battery driving the aspirator fan motor failed. Figure 3 shows the periods of good data for the various sensors. Overall there were about 34 days of 7.5 minute averages, a total of 6664 records. Of these, 1564 contain Dean shield data.

All data were processed with the standard MR program suite and edited. Bad values were replaced with linear interpolated values. Figures 4-7 show the data. The parameter labels are defined below under Data Analysis.

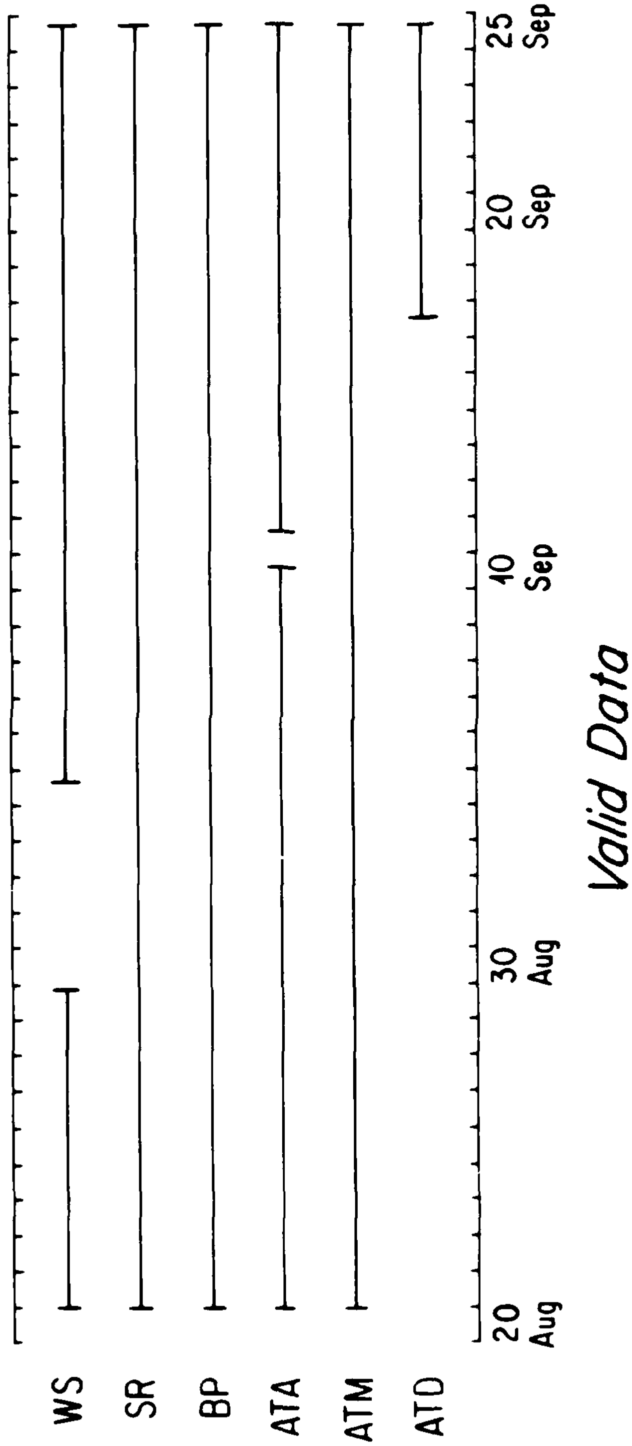


Figure 3

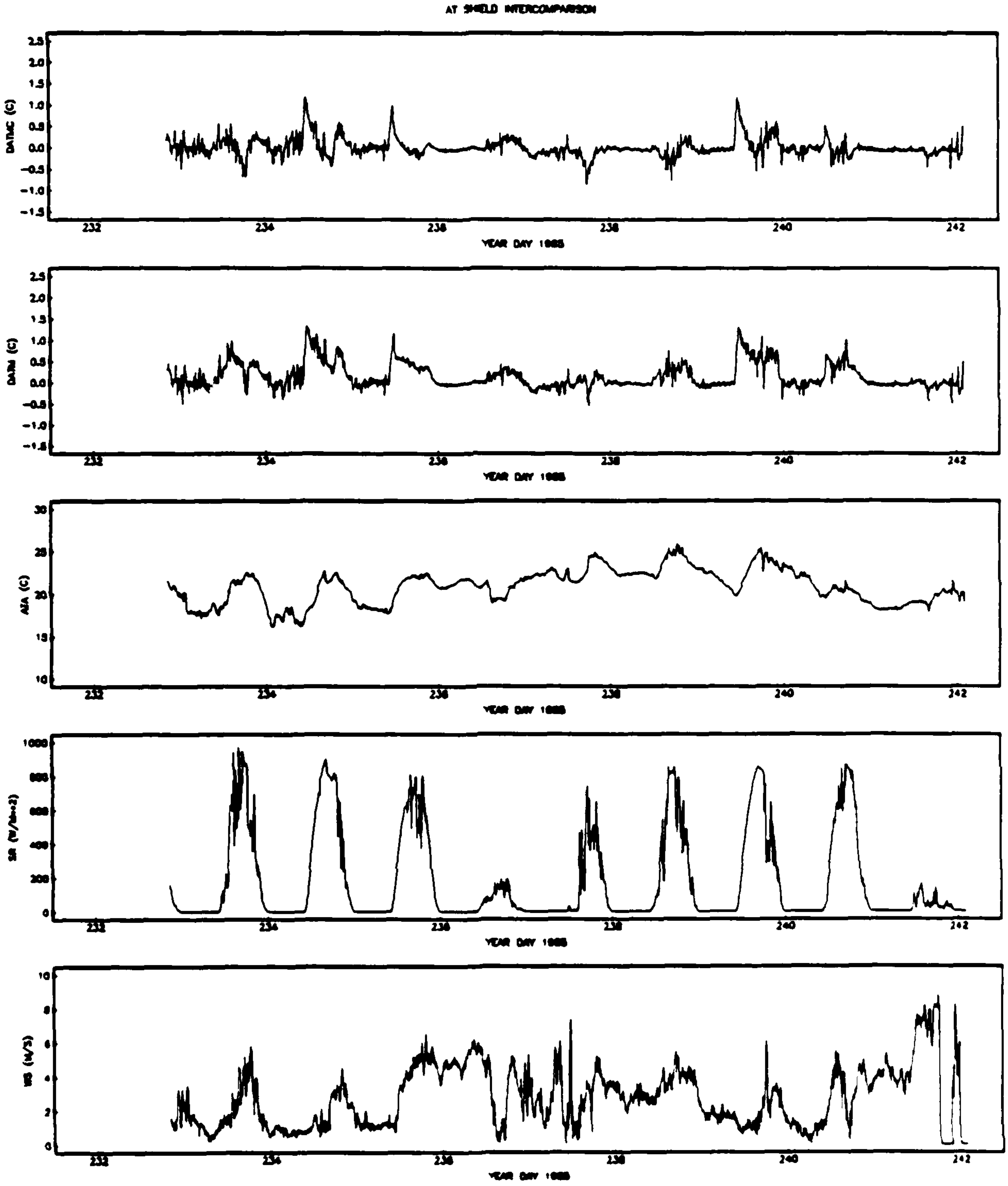
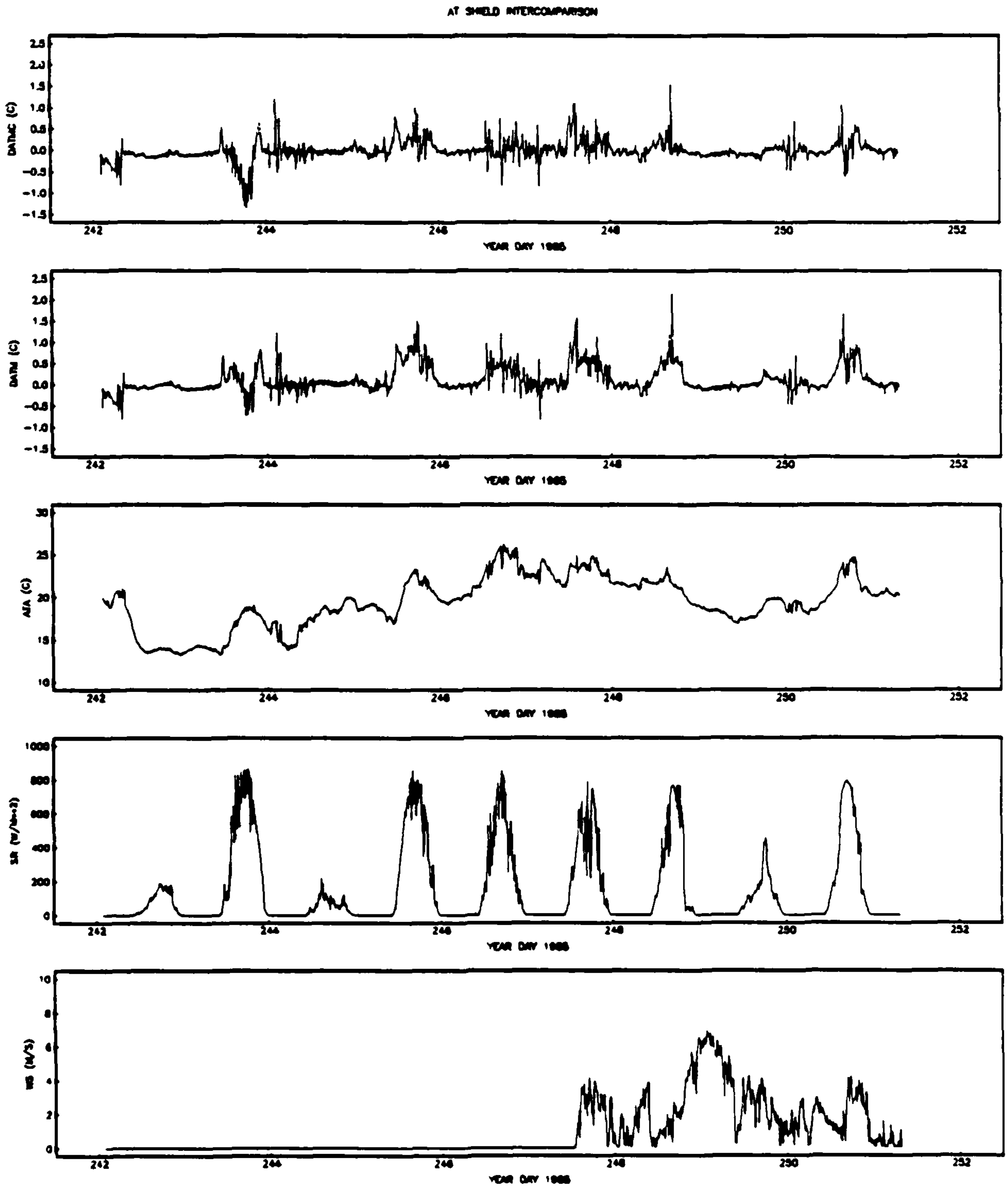

AT SHIELD INTERCOMPARISON
DATMC (C)
DATM (C)
ATA (C)
SR (W/M**2)
WS (M/S)
YEAR DAY 1985
232
234
236
238
240
242

Figure 4



AT SHIELD INTERCOMPARISON
DATMC (C)
DATM (C)
ATA (C)
SR (W/M**2)
WS (M/S)
YEAR DAY 1985

Figure 5

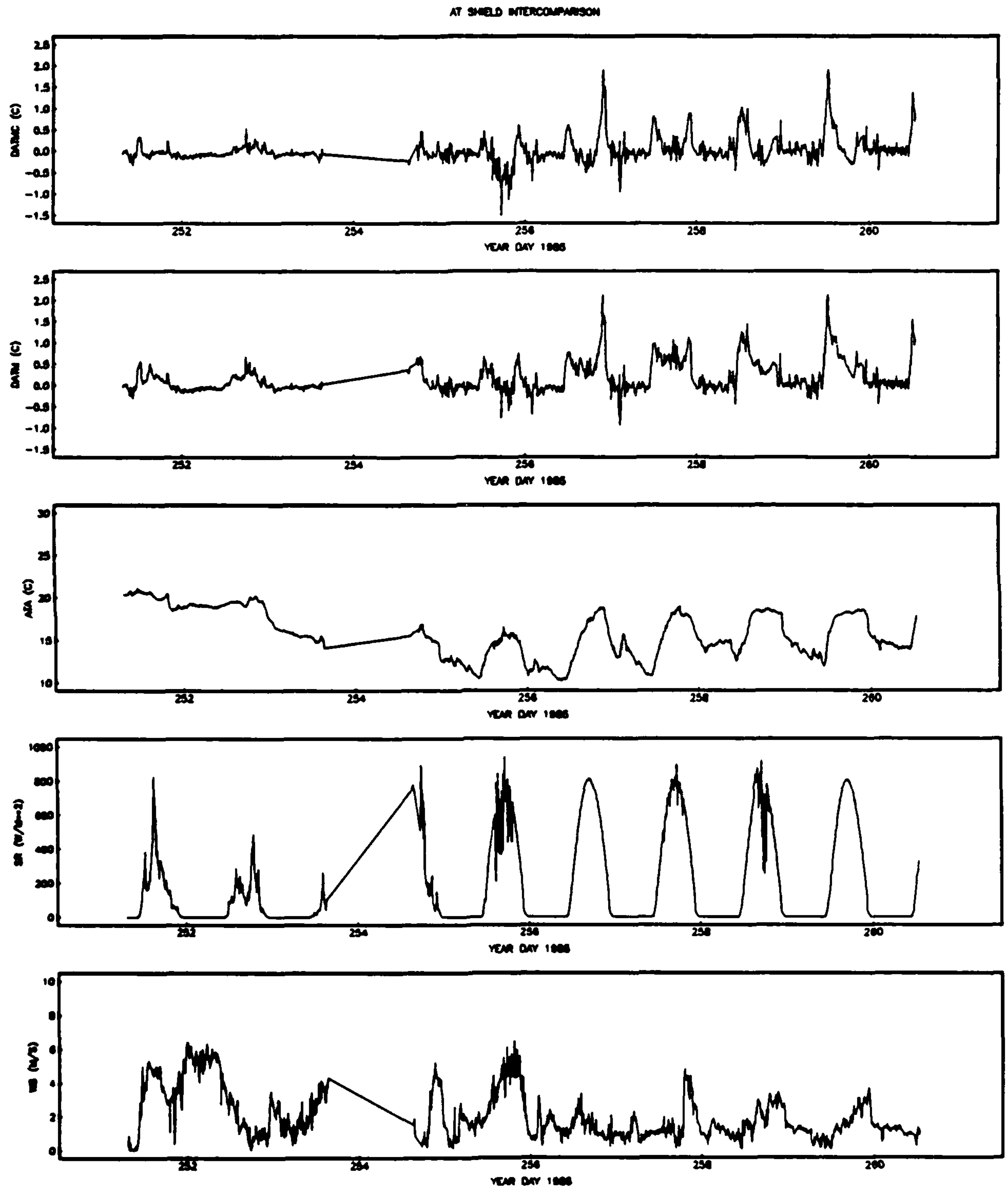


Figure 6

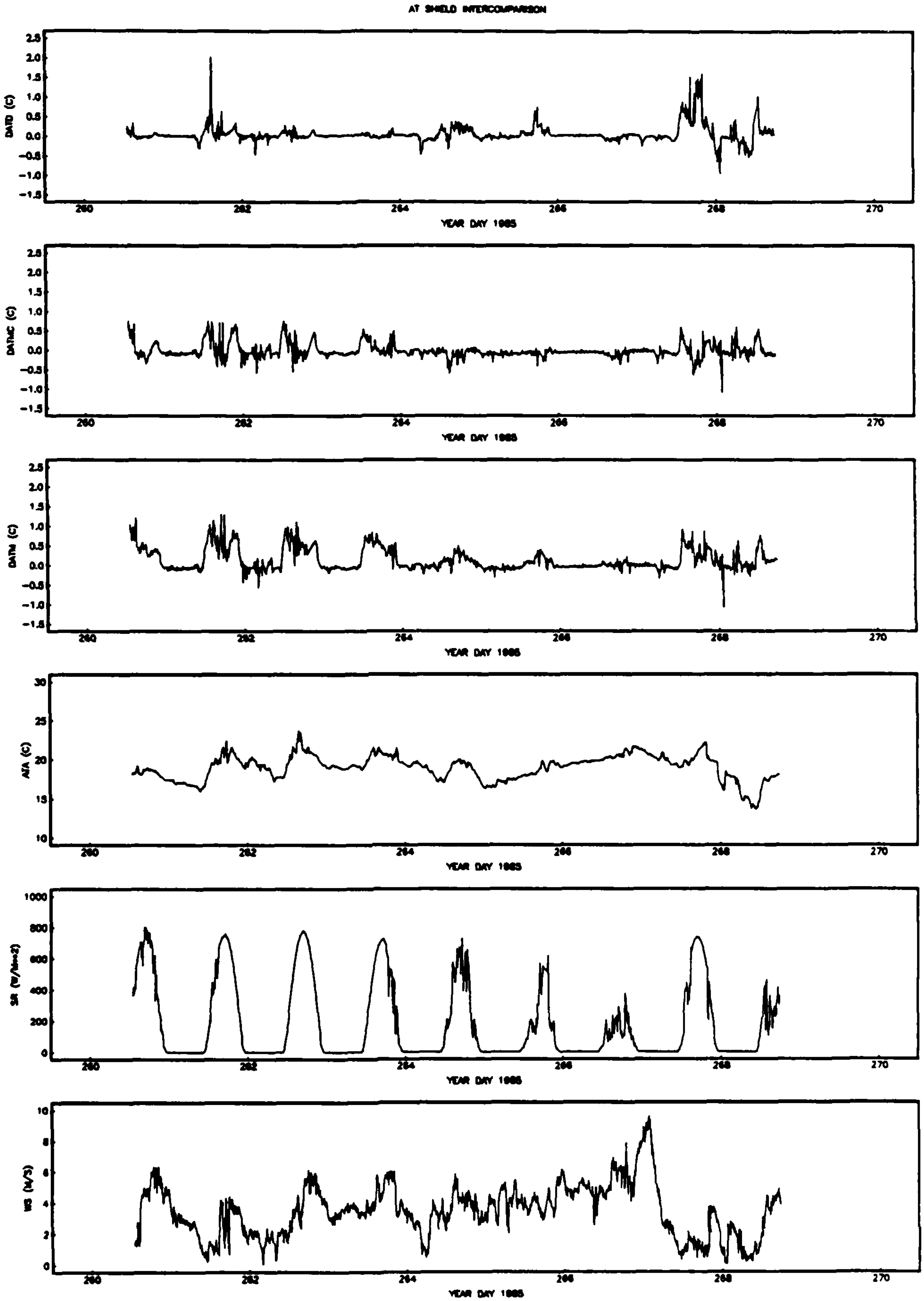

AT SHIELD INTERCOMPARISON
DATD (C)
DATMC (C)
DATM (C)
ATA (C)
WS (M/S)
YEAR DAY 1985
260
262
264
266
268
270

Figure 7

The aspirated air temperature contains a diurnal signal as is expected since air temperatures are normally higher during sunny days than at night. The diurnal signal in DATM and on particularly sunny days with low wind speed, in DATD shows that the aspirated sensor is measuring ambient air temperature better than either of the other two shields.

Data Analysis

Several secondary parameters were computed. Since there was a fairly substantial correlation (.63) between the multiplate temperature differences and solar irradiance we did a least squares fit between the two, obtaining the relation

$$C = 0.012 + 0.7680E\text{-}03{*}SR$$

where SR is irradiance in w m^{-2}. Subtracting this from the original multiplate temperatures gave air temperatures with at least a first order correction for the heating effects of the sun. Since we were interested in whether we could improve air temperatures from the multiplate shield with such a correction we added this parameter to the edited data file as DATMC. No consistent diurnal signal was apparent in the Dean shield temperatures (see Figure 7) so we did not attempt to correct these.

Of primary interest are the errors in the measurements with the shields. The following quantities were computed and all further analysis used them:

WS - Wind speed

SR - Solar irradiance

ATA - Aspirated air temperature

DATM - Multiplate minus aspirated air temperature

DATMC - Multiplate air temperatures corrected for solar irradiance minus aspirated air temperature

DATD - Dean shield minus aspirated air temperatures.

Table 1 contains the mean, standard deviation, and maximum and minimum values of the aspirated air temperature and three temperature differences

Table 1

DATA STATISTICS

	MEAN	SD	MAX	MIN
All data		6664 records		
ATA	18.84	3.06	26.33	10.18
DATM	0.14	0.31	2.15	-1.07
DATMC	0.00	0.24	1.92	-1.50
All night data		3171 records		
ATA	18.06	3.10	24.51	10.18
DATM	-0.04	0.12	1.21	-1.07
DATMC	-0.05	0.12	1.20	-1.08
All Dean shield data		1564 records		
ATA	18.97	1.59	23.65	13.68
DATM	0.14	0.28	1.30	-1.07
DATMC	-0.01	0.19	0.76	-1.08
DATD	0.06	0.23	2.02	-0.94
Dean shield night data		749 records		
ATA	18.37	1.54	21.53	13.68
DATM	-0.05	0.10	0.62	-1.07
DATMC	-0.06	0.10	0.61	-1.08
DATD	-0.02	0.12	0.44	-0.94

for the entire data set, where appropriate, and three subsets: night time (irradiance is less than 2 w m^{-2}) values, full data set; all values during the period that the Dean shield data were recorded; night time (irradiance is less than 2 w m^{-2}) values during the Dean shield period.

When averaged over the whole data set, DATMC is identically zero by definition since that is the data set over which the least squares fit was done. The standard deviation is definitely decreased by correcting for solar irradiance but the improvement is small, an order of magnitude less than we would like. Part of the reason for this is certainly an inadequate amount of data over sufficient ranges of the parameters. Also probably playing a part is a peculiarity of the local weather since Nantucket Sound is decidedly in a sea breeze regime. The correlation between WS and SR is quite apparent in Figures 4-7, particularly on clear days. Since the maximum errors in the multiplate air temperatures occur when the wind speed is low, there are frequently peaks in DATM just after sunrise before the sea breeze has been established and just before sunset when the breeze has decreased. Because of the correlation between WS and SR we cannot separate the effects of these statistically. Qualitatively, however, it appears from this measure that there is a threshold in WS of the order of 2-3 m s^{-1} above which the errors in multiplate air temperatures are 0.5°C or less, and below which they can be much larger.

Gill (1983) describes a study in which he radiated an earlier version of the multiplate radiation shield with artificial solar radiation in a wind tunnel at wind speeds from nearly zero to 3 m s^{-1}. He found sensor temperatures were elevated by 0.5°C at 3 m s^{-1}, 0.7°C at 2 m s^{-1}, 1.3°C at 1 m s^{-1}, and up to 7°C at lower wind speeds. These values are reasonably consistent with ours.

Tables 2-4 and Figures 8-10 show a different representation of the same data. The temperature differences were divided into groups according to wind speed. Within each group we determined minimum and maximum values, the median value, and the upper and lower quartiles (25% of values greater than upper quartile, 25% of values less than lower quartile). Table 2 gives these values for 1 m s^{-1} wind speed ranges for all DATM and DATMC temperature differences, during the full observation period. Table 3 gives the

Table 2

Distribution of Parameters by Wind Speed

20 Aug to 25 Sep, All Data

FILE	WS	NPTS	PARS	MIN	LQ	MED	UQ	MAX
WIND1	0-1	1055	WS	.02	0.44	0.68	0.87	1.00
			DATM	-0.934	-0.145	0.051	0.702	2.129
			DATMC	-0.946	-0.81	0.010	0.380	1.915
WIND2	1-2	1353	WS	1.01	1.21	1.40	1.67	2.00
			DATM	-0.689	-0.050	0.343	0.703	2.114
			DATMC	-0.701	-0.077	-0.007	0.101	1.909
WIND3	2-3	876	WS	2.01	2.27	2.55	2.78	3.00
			DATM	-1.068	-0.051	0.010	0.361	2.146
			DATMC	-1.080	-0.096	-0.042	0.049	1.549
WIND4	3-4	969	WS	3.01	3.25	3.48	3.73	4.00
			DATM	-0.540	-0.040	0.083	0.406	1.282
			DATMC	-0.830	-0.095	-0.043	0.063	0.710
WIND5	4-5	720	WS	4.01	4.23	4.47	4.72	5.00
			DATM	-0.439	-0.042	0.043	0.306	1.300
			DATMC	-0.934	-0.114	-0.062	0.027	0.709
WIND6	5-6	408	WS	5.01	5.21	5.42	5.63	6.00
			DATM	-0.514	-0.071	-0.013	0.333	0.879
			DATMC	-1.044	-0.129	-0.074	-0.028	0.415
WINDX	6-10	195	WS	6.01	6.23	6.74	7.75	9.56
			DATM	-0.762	-0.086	-0.011	0.028	0.582
			DATMC	-1.495	-0.132	-0.068	-0.019	0.218

MIN = MINIMUM
LQ, UQ = LOWER, UPPER QUARTILE
MED = MEDIAN
MAX = MAXIMUM

Table 3

Distribution of Parameters by Wind Speed

20 Aug to 25 Sep, Daytime data only, (SR is greater than 2 w m^{-2})

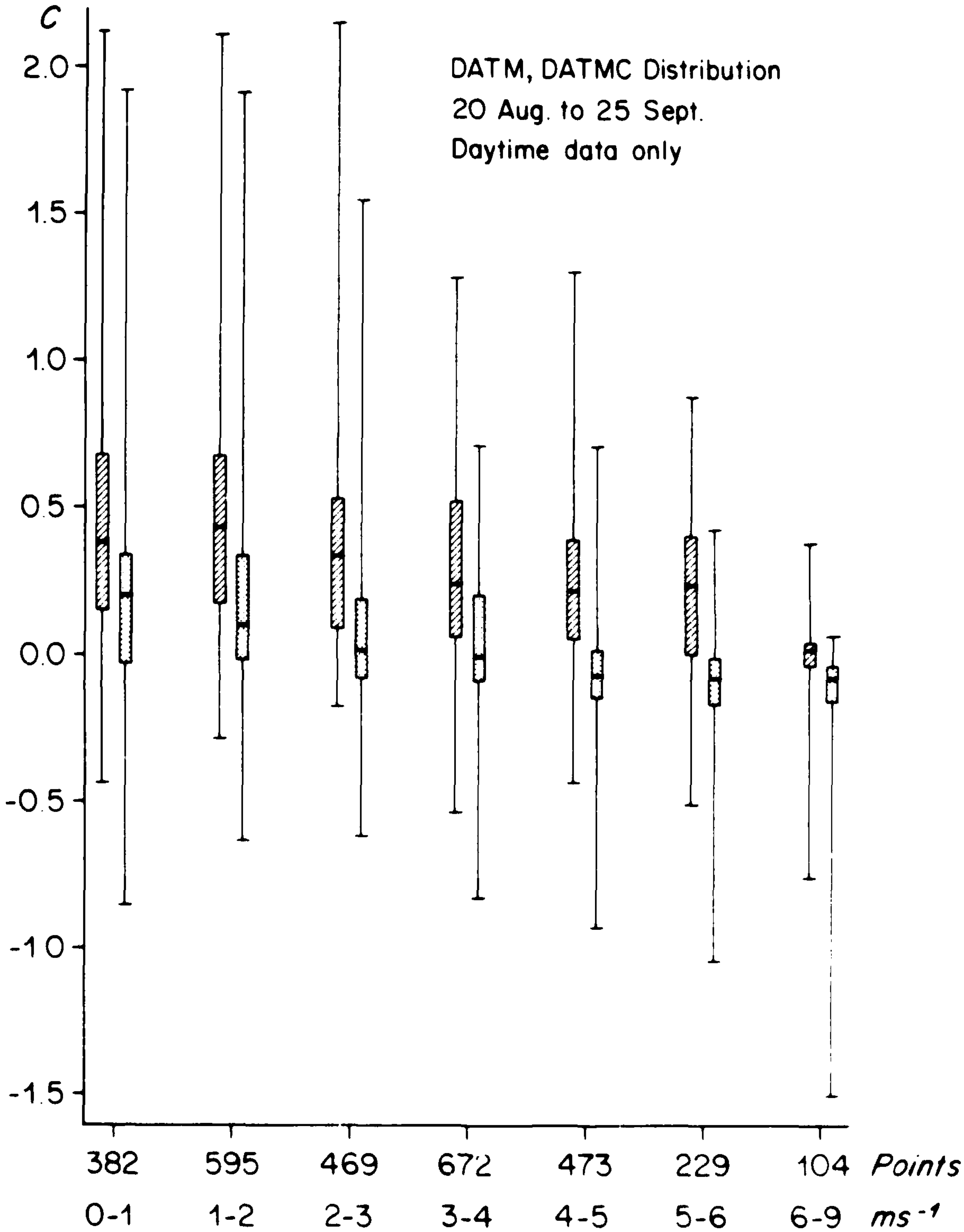
FILE	WS	PAR	NPTS	MIN	LQ	MED	UQ	MAX
WIND1	0-1	WS	382	0.02	0.49	0.74	0.89	1.00
		DATM	382	-0.439	0.145	0.378	0.684	2.129
		DATMC	382	-0.846	-0.034	0.195	0.338	1.915
WIND2	1-2	WS	595	1.01	1.23	1.45	1.69	2.00
		DATM	595	-0.288	0.174	0.430	0.670	2.114
		DATMC	595	-0.631	-0.020	0.098	0.329	1.909
WIND3	2-3	WS	469	2.01	2.28	2.56	2.80	3.00
		DATM	469	-0.179	0.085	0.326	0.534	2.146
		DATMC	469	-0.624	-0.079	0.013	0.188	1.549
WIND4	3-4	WS	672	3.01	3.25	3.49	3.74	4.00
		DATM	672	-0.540	0.059	0.242	0.523	1.282
		DATMC	672	-0.830	-0.094	-0.011	0.199	0.710
WIND5	4-5	WS	473	4.01	4.23	4.44	4.70	5.00
		DATM	473	-0.439	0.045	0.205	0.386	1.300
		DATMC	473	-0.934	-0.150	-0.066	0.011	0.709
WIND6	5-6	WS	229	5.01	5.18	5.40	5.61	6.00
		DATM	229	-0.514	0.000	0.233	0.397	0.879
		DATMC	229	-1.044	-0.166	-0.076	-0.010	0.415
WIND7	6-9	WS	104	6.01	6.30	6.89	7.45	8.75
		DATM	104	-0.762	-0.038	0.013	0.044	0.582
		DATMC	104	-1.495	-0.158	-0.079	-0.039	0.072

Table 4

Distribution of Parameters by Wind Speed

17-25 Sep, Daytime data only (SR is greater than 2 w m^{-2})

FILE	WS	PAR	NPTS	MIN	LQ	MED	UQ	MAX
WIND1	0-1	WS	53	0.22	0.61	0.78	0.87	0.98
		DATM	53	-0.150	-0.029	0.178	0.485	1.025
		DATMC	53	-0.423	-0.141	-0.084	0.035	0.615
		DATD	53	-0.46	-0.09	0.36	0.96	1.75
WIND2	1-2	WS	97	1.01	1.22	1.41	1.68	1.99
		DATM	97	-0.108	0.218	0.522	0.636	1.150
		DATMC	97	-0.631	-0.036	0.186	0.382	0.750
		DATD	97	-0.45	0.06	0.21	0.51	2.02
WIND3	2-3	WS	68	2.03	2.41	2.64	2.82	2.99
		DATM	68	-0.168	0.054	0.153	0.682	0.991
		DATMC	68	-0.556	-0.029	0.049	0.445	0.760
		DATD	68	-0.15	0.04	0.10	0.24	1.04
WIND4	3-4	WS	238	3.01	3.34	3.55	3.79	4.00
		DATM	238	-0.119	0.083	0.256	0.540	1.282
		DATMC	238	-0.416	-0.074	0.002	0.231	0.710
		DATD	238	-0.08	0.04	0.10	0.19	1.18
WIND5	4-5	WS	195	4.01	4.23	4.47	4.71	5.00
		DATM	195	-0.212	0.071	0.196	0.432	1.300
		DATMC	195	-0.365	-0.139	-0.062	0.017	0.709
		DATD	195	-0.08	0.00	0.04	0.11	0.38
WIND6	5-6	WS	125	5.01	5.25	5.49	5.67	6.00
		DATM	125	-0.217	0.051	0.328	0.440	0.836
		DATMC	125	-0.595	-0.133	-0.065	0.001	0.360
		DATD	125	-0.33	-0.03	0.00	0.02	0.09
WIND7	6-8	WS	40	6.01	6.18	6.31	6.62	7.82
		DATM	40	-0.204	-0.015	0.018	0.055	0.520
		DATMC	40	-0.362	-0.175	-0.108	-0.049	0.072
		DATD	40	-0.20	-0.08	-0.03	0.00	0.07



C
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
DATM, DATMC Distribution
20 Aug. to 25 Sept.
Daytime data only
382 595 469 672 473 229 104 Points
0-1 1-2 2-3 3-4 4-5 5-6 6-9 ms-1

Figure 8

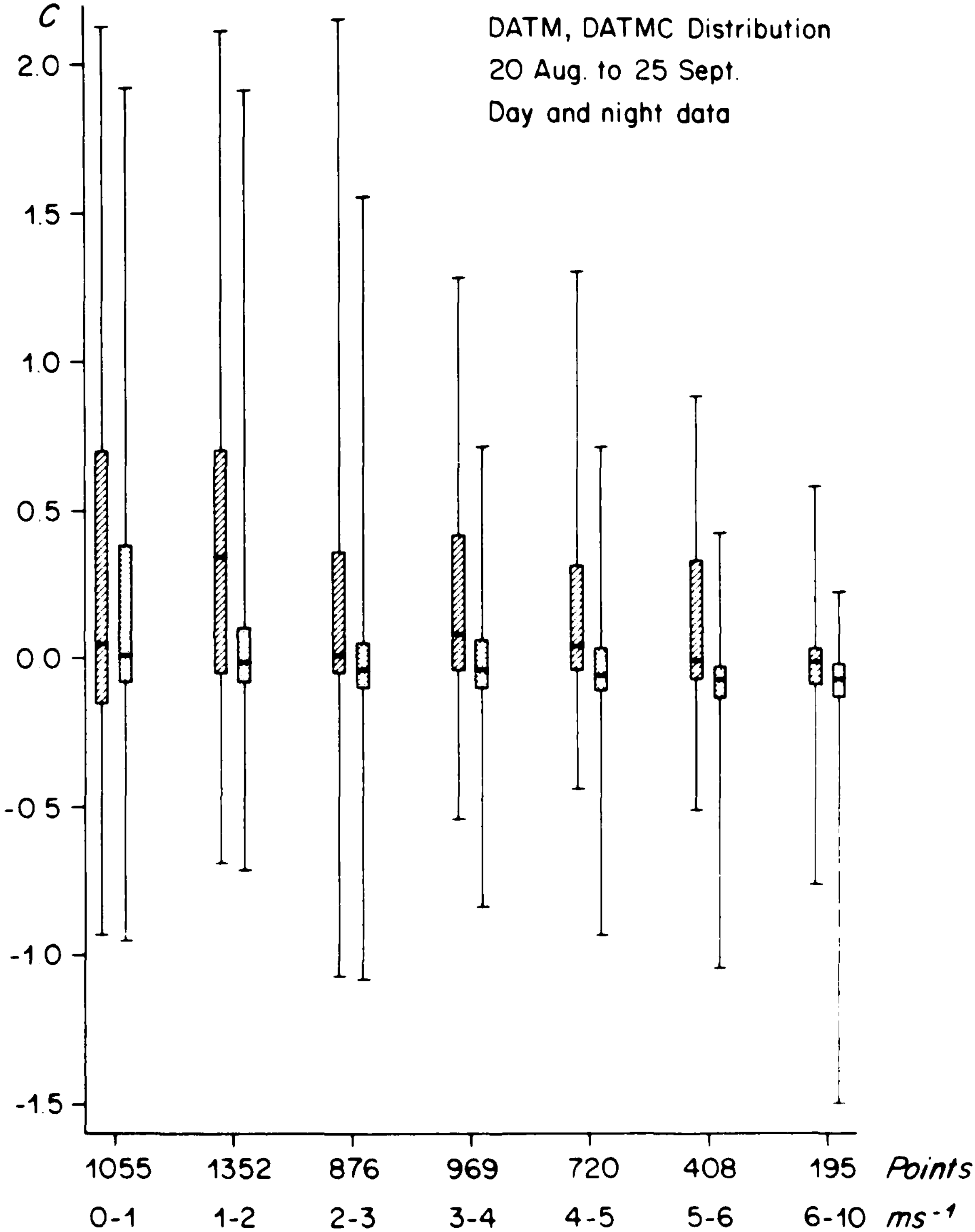

C
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
DATM, DATMC Distribution
20 Aug. to 25 Sept.
Day and night data
1055 1352 876 969 720 408 195 Points
0-1 1-2 2-3 3-4 4-5 5-6 6-10 ms-1

Figure 9

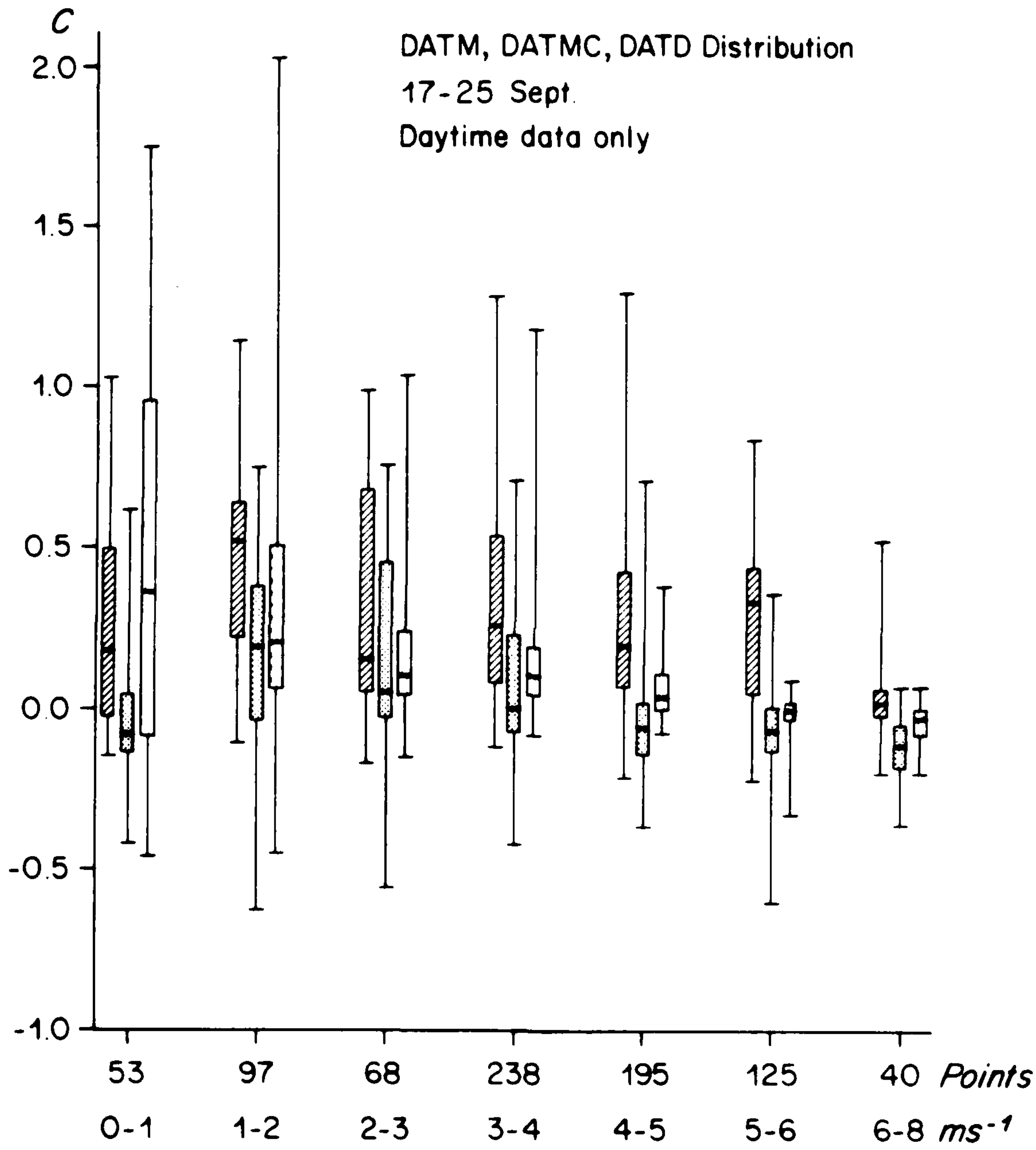

C
DATM, DATMC, DATD Distribution
17-25 Sept.
Daytime data only
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
53
97
68
238
195
125
40 Points
0-1
1-2
2-3
3-4
4-5
5-6
6-8 ms-1

Figure 10

values for daytime (SR is greater than 2 w m^{-2}) DATM and DATMC only. Table 4 gives the values for daytime DATM, DATMC, and DATD for the period when the Dean sensor was connected. Figures 8-10 are box plots of the same numbers. The boxes give the upper and lower quartiles; thus the line toward the middle of a box indicates the median. Fifty per cent of the values in a wind speed range lie within a box. Below each box are given the wind speed range and the number of samples in that speed range.

For ideal shields the boxes in Figures 8-10 would all collapse on zero. It is apparent that the correction does improve the temperatures from the multiplate shield since, for all wind speed ranges on all plots the median is closer to zero and the extent of the box is decreased for the corrected values. The improvement is most apparent on Figures 8, 9 although it is perceivable even in the reduced data set represented on Figure 10.

The performance of both types of radiation shields improves with increasing wind speed. For wind speeds greater than 6 m s^{-1}, the performance of both types appears to be equivalent. In the wind speed range 2-6 m s^{-1}, the Dean shield seems to protect the thermistor better than the multiplate shield. For wind speeds less than 2 m s^{-1}, the multiplate shield does better, presumably because at these low speeds there is not enough wind force on the Dean shield to overcome the bearing friction and turn it into the wind.

Conclusions

We have presented the results of an informal study of the performance of R. M. Young multiplate radiation shields and a shield designed and constructed at WHOI (Dean shield). Both shields gave errors of up to 1-2°C, however the Dean shield seemed to perform better in wind speeds of more than 2 m s^{-1}. The error in air temperature measurement by a thermistor in either type of shield depends on both solar radiation and wind speed the error increasing with increasing solar irradiance and decreasing with increasing wind speed. It may be possible to generate a meaningful correction to air temperatures measured with the multiplate radiation shield which is a function of irradiance and wind speed. A correction based on data recorded in this study makes a noticeable improvement in air temperature measurement

accuracy. The small range in values of irradiance and wind speed and the correlation between irradiance and wind speed means that the correction we have derived is much less than optimal. A better correction would require a much more extensive study.

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Measurements were made with a group of sensors for 37 days at the end of a dock in Vineyard Sound. The sensors included: a thermistor in an R. M. Young aspirated air temperature radiation shield, a thermistor in an R. M. Young multiplate shield, wind speed and direction, and solar irradiance. For the last eight days we also included a WHOI built cylindrical radiation shield. For wind speeds above 2 m s^{-1}, the multiplate shield had an RMS error relative to the aspirated shield of 0.2-0.3 C during daylight hours. Adding a correction linear in solar irradiance decreased the error by a factor of one third to one half. The cylindrical shield appears to have performed better than this but there was insufficient data to support this conclusion statistically.

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